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## FOREWORD

The crystal detector is almost as old as radio itself. In every generation since the early days of wireless, thousands of enthusiastic adults and youngsters have constructed crystal sets and picked up signals with them. The fascination of the crystal seems to be endless.

For a long time after vacuum tubes became sufficiently low-priced for experimenters to afford them in numbers, the crystal came to be looked upon as a fragile novelty with few practical applications outside of the toy radio receiver field. By the end of World War II, however, the highly stable germanium crystal diode was available. This device, typified by the popular Sylvania 1N34, has restored the crystal to a position of importance in the electronic field. Many useful tubeless devices now may be constructed around crystal diodes.

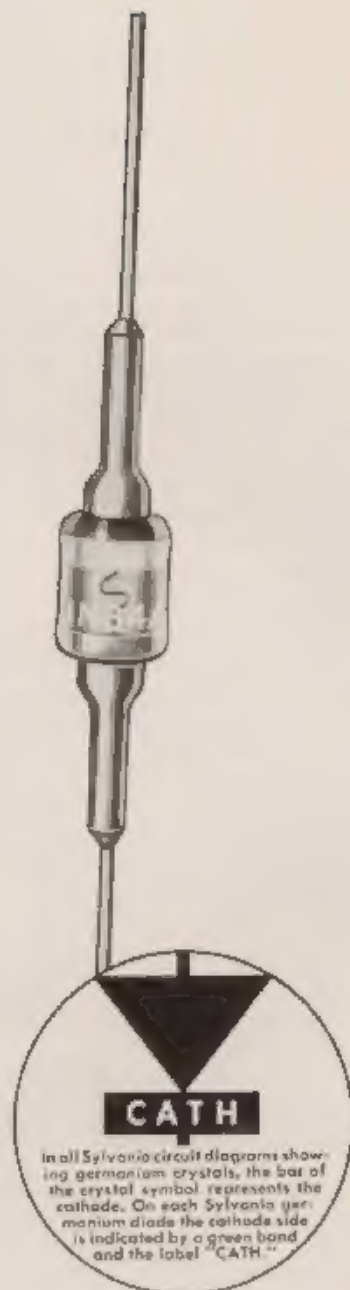
Sylvania has carried on considerable research into the production of better germanium diodes and from time to time has published pamphlets showing new and interesting applications of these crystals. This latest booklet brings together the largest published collection to date of miscellaneous crystal diode applications.

In this booklet will be found receiver, transmitter and amplifier applications, instruments, and gadgets. It has been our aim to present a variety of applications in each of which one of the various distinct groups of radio people might find interest. The casual hobbyist and young experimenter will find on these pages interesting gadgets he can build—and the serious technician will find time-saving devices and simplified circuits to serve him.

No license is to be implied with respect to any inventions described herein, and no responsibility is assumed for the application or interpretation of the information contained herein, or for any infringement of patent or other rights of third parties which may result from the use of that information.

All of the circuits described have been tested and proved. Since it has been impossible to include every possible crystal application, we have selected the most generally useful ones from our large collection.

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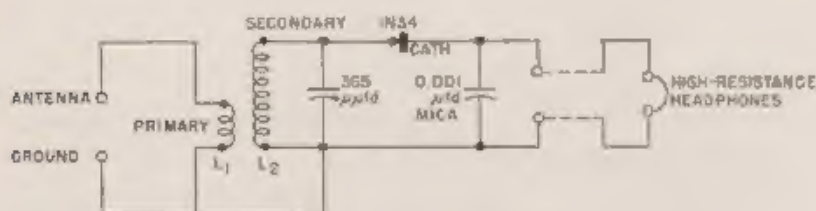


## CHAPTER I

### RECEIVERS AND RECEIVER APPLICATIONS

**1.1 SIMPLE CRYSTAL RECEIVER.** The crystal receiver has had universal appeal to a multitude of radio experimenters since the early days of wireless. Its continued fascination, even at present when tubes are inexpensive, has been due to the fact that the crystal detector requires no power supply and gives remarkably clear and lifelike reproduction. Furthermore, a crystal set is simple in principle and easy to build.

The audio output of a crystal set is low. This means that a good, long, outside antenna and a good ground must be used in most localities for best results. These requirements do not detract from the popularity of this simple receiver, however, and thousands are built each year by hobbyists in all walks of life.



L<sub>1</sub> AND L<sub>2</sub> ARE THE PRIMARY AND SECONDARY OF ANTENNA COIL WITH FREQUENCY RANGE OF 540-1750 KC

Figure 1-1. SIMPLE CRYSTAL RECEIVER

Figure 1-1 shows one of the simplest circuits which may be employed to receive broadcast stations. A set of this type may be built in a single evening by an inexperienced person. While the reader might wind his own coils, the manufactured coil specified in Figure 1-1 is so low in price as to make the labor of making the coil at home unattractive.

The set covers the standard broadcast band. That is, 540 to 1750 kc which is actually a little more than the broadcast band limits. All tuning is done with the single 365-µfd variable capacitor.

Under ordinary conditions, the range of the receiver will not be greater than about 25 miles. Loudest signals will be picked up from the most powerful stations. Best signal strength will be obtained when the antenna is outside, between 40 and 100 feet long, and situated as high as practicable above the ground and other objects. A good ground, such as a tight connection to a cold water pipe, might be used.

**1.2 PUSH-PULL CRYSTAL RECEIVER.** The crystal receiver circuits shown in Figure 1-2 deliver somewhat louder signals than the simpler sets described in Section 1.1, and separates stations more effectively.

The improved operation of this circuit is obtained by use of double tuning (by means of tuning capacitors  $C_1$  and  $C_2$ ) and two crystal diodes in a full-wave detector circuit. If desired, a Sylvania Type 1N35 duo-diode unit may be used in place of the two separate 1N34's. Details of the special coupling coil, which can be built easily by the reader, are given in Figure 1-2.

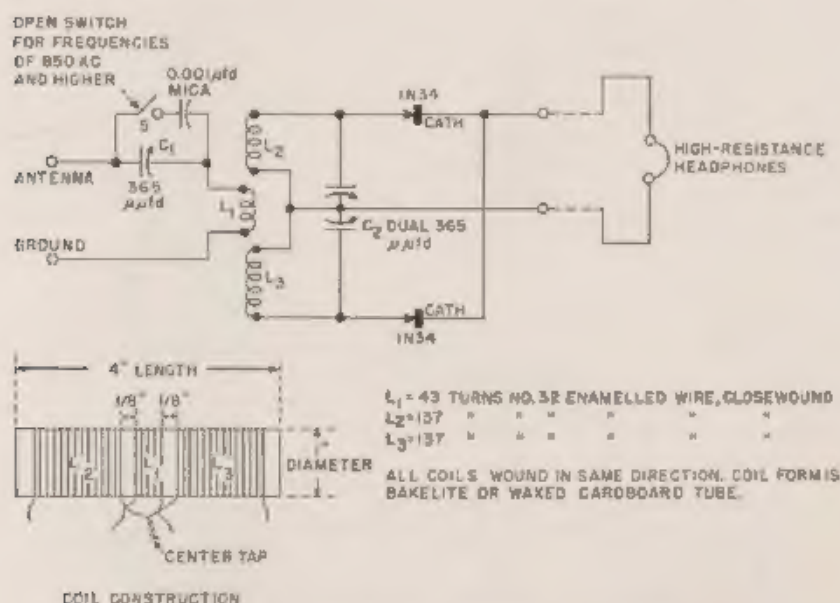


Figure 1-2. PUSH-PULL CRYSTAL RECEIVER

Operation of the set is not complicated. (1) If the station to be received operates on a frequency lower than 850 kc, close switch S. If the station frequency is 850 kc or higher, open the switch. (2) Tune-in the station closely by adjusting capacitor  $C_2$ . (3) Finally, adjust capacitor  $C_1$  to improve the headphone volume and to reduce at the same time interference from other stations.

**1.3 BANDPASS CRYSTAL RECEIVER.** A highly-selective crystal broadcast receiver circuit is shown in Figure 1-3. The ability of this circuit to separate stations more effectively than earlier sets is made possible by a tuned bandpass filter made up with manufactured coils. These coils are obtainable as a kit. Single-dial tuning is entirely by means of the dual 365-μfd variable capacitor.

#### SHIELDED ANTENNA COIL WITH FREQUENCY RANGE OF 540-750 KC

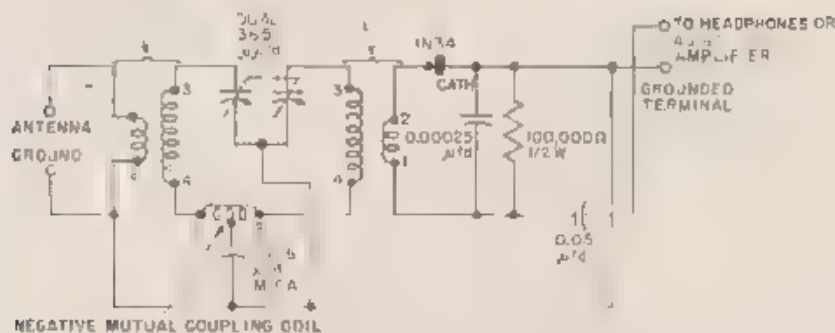


Figure 1-3. BAND PASS CRYSTAL RECEIVER

The audio output of this circuit is somewhat lower than that afforded by the receivers described in Sections 1.1 and 1.2. However, the circuit was designed originally for use as a broadcast tuner to be used with a high fidelity audio amplifier. The amplifier gain compensates for the low volume of the crystal detector output.

#### 1.4 USE OF AUDIO AMPLIFIERS WITH CRYSTAL SETS.

While crystal receivers ordinarily are thought of as being used with headphones, any crystal set may be used ahead of an audio amplifier when loudspeaker operation is desired. Because of the increased linearity of the crystal detector at low signal levels, a combination of crystal receiver and audio amplifier will give true-to-life reproduction.

**1.5 CRYSTAL VIDEO DETECTOR.** Because the dynamic resistance of the germanium crystal diode is very low and the crystal capacitance also is low, the crystal diode offers improved operation in video second detector circuits in television receivers. The crystal diode also gives excellent linearity at low signal levels and is free from contact potential effects.

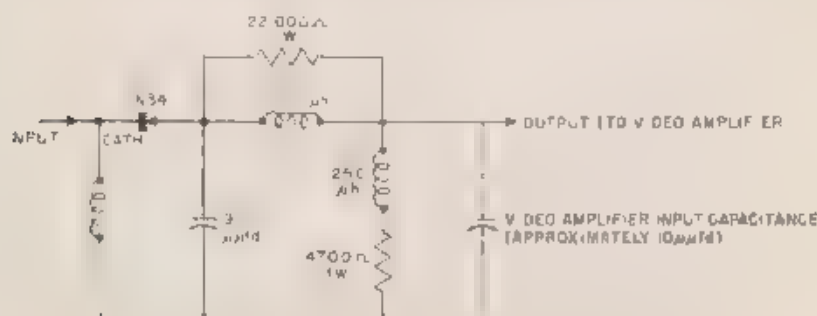


Figure 1-4. CRYSTAL VIDEO DETECTOR FOR TELEVISION

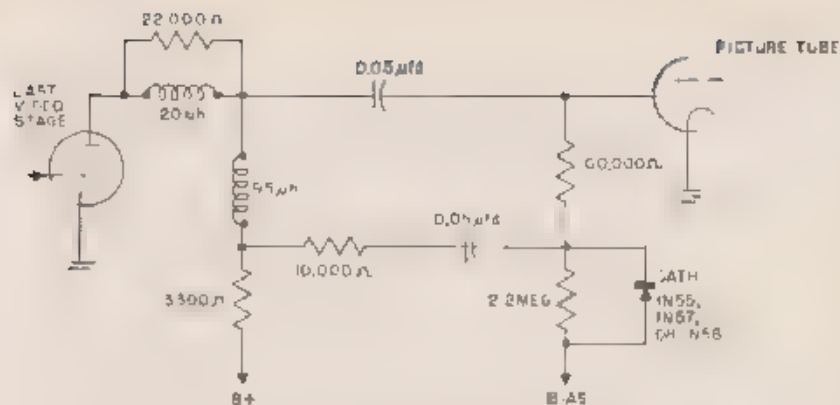


Figure 1-5. CRYSTAL DC RESTORER FOR TELEVISION

Figure 1-5 is the circuit of a video detector employing the 1N34. This circuit will be of interest to builders of home-made television receivers who wish to reduce the amount of tube space on the chassis, while at the same time taking advantage of the additional improvements offered by the crystal detector.

**1.6 CRYSTAL DC RESTORER FOR TELEVISION.** The function of dc restoration in a television receiver is accomplished proficiently by a crystal diode because of its low dynamic resistance.

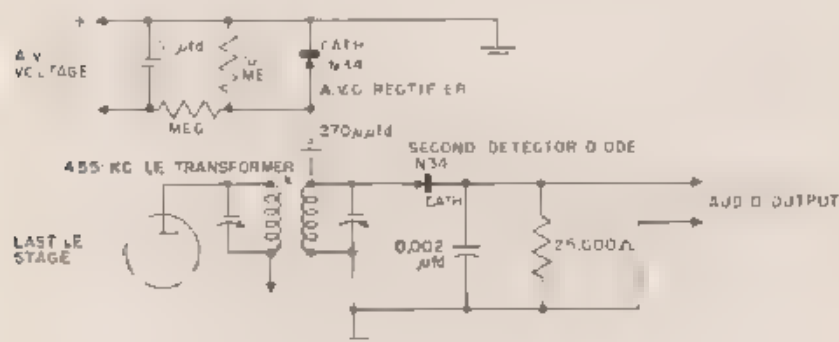


Figure 1-6. SECOND DETECTOR—A.V.C. CIRCUIT

Figure 1-5 shows a typical dc restorer circuit. Several new crystal diodes developed by Sylvania have the ability to withstand relatively high negative dc voltages and are well suited to use in the dc restorer circuit. These new diodes are the 1N55 which is rated at 150 volts, 1N57 at 80 volts, and 1N58 at 100 volts.

**1.7 SECOND DETECTOR—AVC CIRCUIT.** Considerable space saving and circuit simplification are made possible in the radio receivers, especially in short wave and all-wave sets, by using crystal diodes as 2nd detector and avc rectifiers.

In Figure 1-6, one 1N34 is employed as a series-diode 2nd detector, and a second 1N34 as a shunt-diode avc rectifier. The capacitance and resistance values given in this circuit are for the popular 455 kc intermediate frequency.

The crystal diodes may be mounted under the chassis of the receiver with the capacitors and resistors associated with the circuit.

**1.8 FM DETECTORS.** Germanium diodes simplify the circuits and construction of the frequency modulation 2nd detectors. The 1N35 duo-

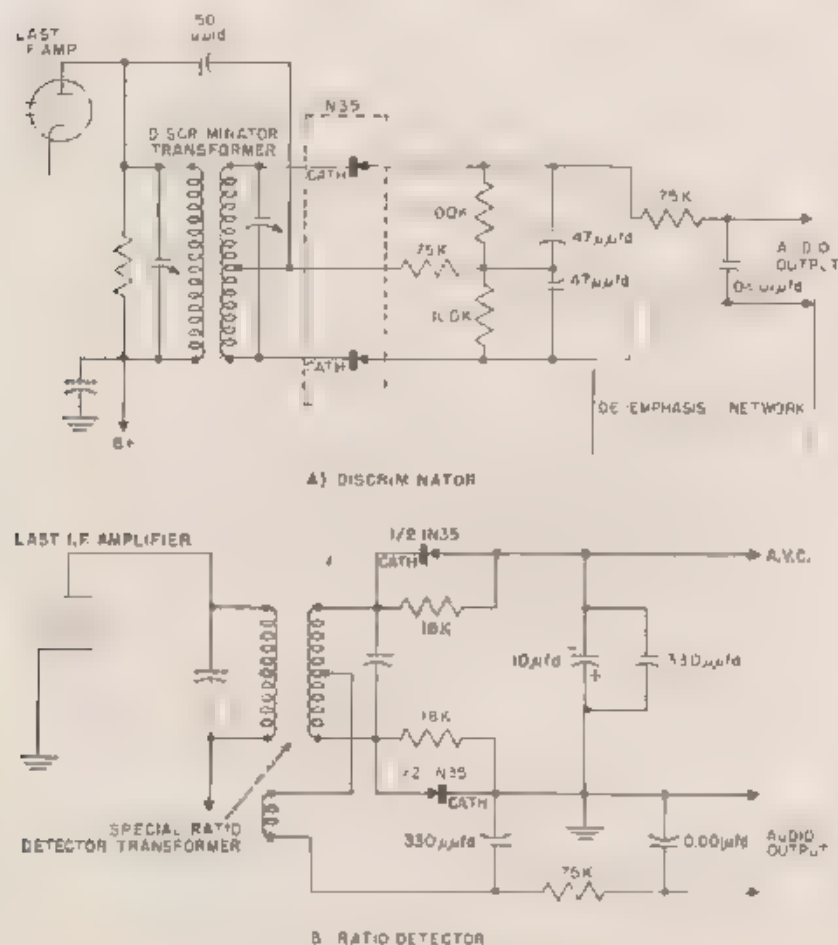


Figure 1-7. FM DETECTORS

diode, consisting of two factory-matched crystals, is especially suitable for this application.

Figure 17 shows the connection of the crystals in discriminator (A) and modified ratio detector (B) circuits for second detectors in both FM broadcast receivers and in the sound channels of television sets. Circuit B is a special adaptation of the conventional ratio detector for use with 1N34 or 1N35 crystals. Both of these circuits are suited for  $f$  frequencies of the order of 10 to 30 megacycles.

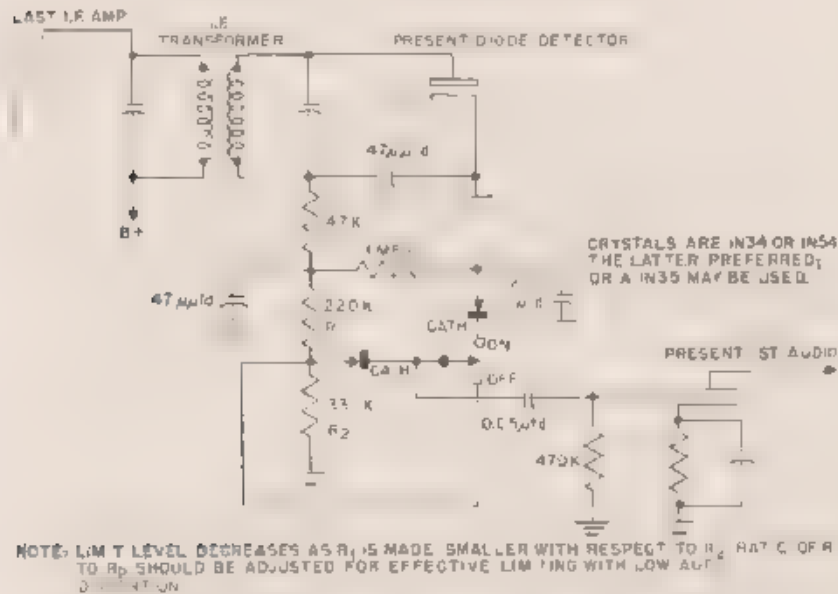


Figure 1-8. SHUNT IMPULSE NOISE LIMITER

### 1.9 COMPACT SERIES—SHUNT IMPULSE NOISE LIMITER.

Figure 1-8 shows the use of two 1N34 and 1N54 crystals, or a single 1N35 duo-diode unit, in a compact yet extremely effective impulse noise limiter of the series-shunt or compound type. This simple limiter can be installed in a communications receiver in a short time. Once installed and adjusted, it requires no further attention, since it is self-adjusting to various strengths of signal, and various noise conditions.

All of the parts, including the crystals, may be mounted on a small bakelite strip and should be enclosed in a metal shield can, to prevent hum pickup. The single-pole-double-throw switch allows the limiter to be cut out when not needed.

This simple noise limiter will be found extremely effective in the reduction of ignition interference in mobile receiver installations.





## CHAPTER 2

### TRANSMITTER AND AMPLIFIER APPLICATIONS

**2.1 TRANSMITTER FAILURE ALARM.** It often is necessary to alert transmitting station personnel other than operators in the transmitter operating room when the station accidentally leaves the air. A monitoring receiver tuned to the transmitter frequency ordinarily is used, but this is not always a desirable method. A continuously running receiver can become a nuisance.

Figure 2-1 is the circuit for an automatic alarm which goes into operation whenever the carrier is interrupted. No direct connection to the transmitter is required. The crystal detector simplifies receiver and control circuits.

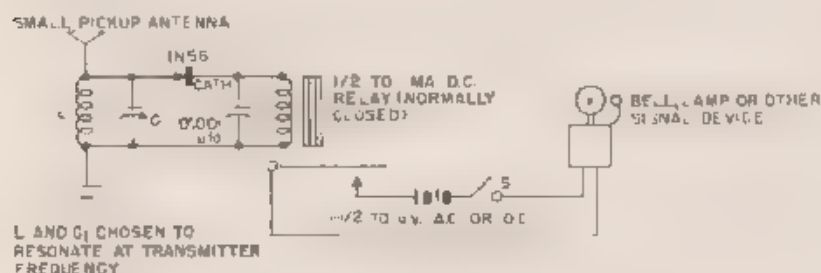


Figure 2-1. TRANSMITTER FAILURE ALARM

The values of coil L and variable capacitor  $C_1$  are selected to tune to the station frequency.  $C_1$  can be a screwdriver-adjusted trimmer. A 1N56 high-conduction diode is employed to insure maximum possible relay current. The pickup antenna may be a short inside or outside antenna, as receiving conditions dictate, or it may be a short vertical rod.

When the station is on the air, the relay will be energized by the crystal diode and the relay contacts will open. Switch S then is closed manually. If the station goes off the air, current will cease to flow through the relay coil, the contacts will close, and the alarm device (bell, horn, or lamp) will be operated.

**2.2 TRANSMITTER ADJUSTING GIMMICK.** The untuned, rf-operated crystal device illustrated in Figure 2-2 will find a host of uses in transmitter tuning-up and adjustment. When the small pickup coil is held near the plate or grid coil in any transmitter stage, it will pick up a small rf voltage which will be rectified by the 1N34 and caused to deflect the milliammeter. Adjustment of the 1000-ohm rheostat will prevent "pinning" of the meter by strong signals.

This gadget may be used as an rf indicator in neutralizing adjustments, stage tuning, exploring for parasites and stray rf, and testing

the effectiveness of shielding. Many other applications will occur to the reader. Headphones may be plugged into the jack for aural monitoring of amplitude modulated signals and for hum and noise tracing in transmitter stages.

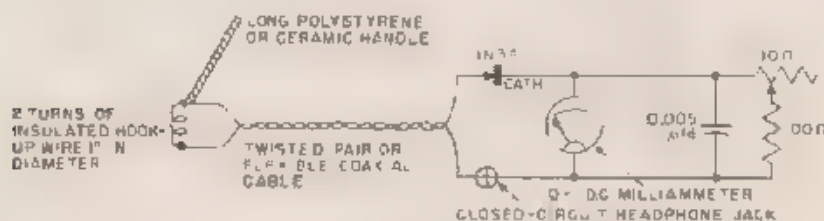


Figure 2-2. TRANSMITTER ADJUSTING GIMMICK

**2.3 LOW-POWERED FREQUENCY DOUBLER.** Where space is at a premium, frequency doubling can be achieved by means of a pair of crystal diodes in the circuit shown in Figure 2-3. This circuit operates on the principle that the output of a full-wave rectifier has twice the frequency of the ac input voltage. The doubling action is enhanced by the tank circuit  $L_2-C_2$  which is tuned to twice the input frequency. The input tank circuit ( $L_1-C_1$ ) is tuned to the input frequency. Two of these simple doubler stages in cascade will quadruple the input frequency.

Because of the low power-handling ability of the crystal diodes,

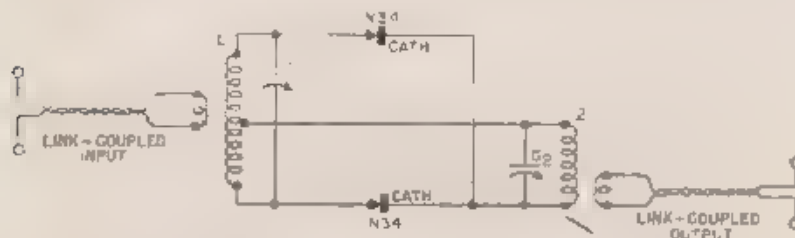


Figure 2-3. LOW-POWERED FREQUENCY DOUBLER

operation of this circuit is limited to input power levels of less than 1 watt. The crystal doubler accordingly can be used only ahead of pentode or beam power rf amplifiers having very high power sensitivity (that is, amplifiers requiring low grid driving power). Slightly higher power ratings are obtained with a pair of 1N56 diodes.

The crystal doubler is suitable for operation at frequencies up to 200 megacycles.

**2.4 CARRIER-OPERATED INVERSE FEEDBACK CIRCUIT.** Inverse feedback is invaluable in a modulated transmitter for improving quality and reducing hum and noise. It is not so easily applied, how-

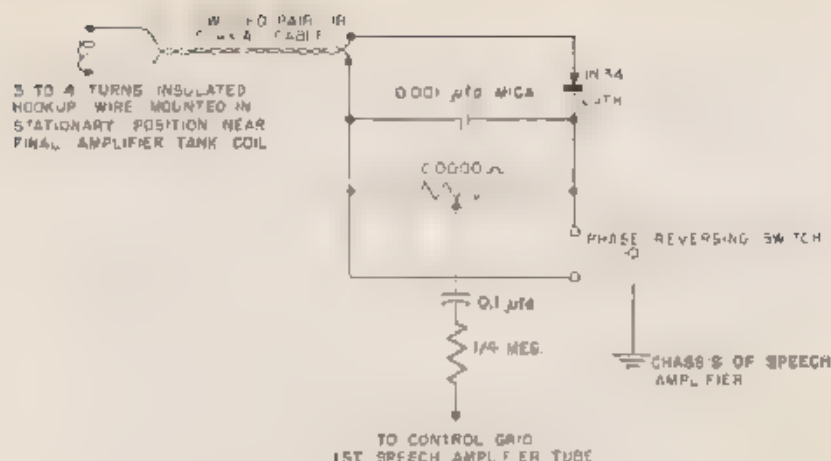


Figure 2-4. CARRIER OPERATED INVERSE FEEDBACK CIRCUIT

ever, to efficiency-modulated circuits, such as grid-modulated, screen-modulated, cathode-modulated, and class-B linear amplifiers.

The crystal circuit shown in Figure 2-4 overcomes this difficulty by sampling the feedback signal. The picked-up rf is demodulated by the crystal, and the audio voltage obtained by this process is applied in the control grid of the first speech amplifier tube. The 100 000-ohm potentiometer enables the operator to adjust the fed-back audio voltage to the proper level for best results.

When using this system, it is advisable not to include more than one iron-core transformer in the feedback loop. If oscillation occurs, throw the phase reversing switch to its opposite position.

**2.5 PREMODULATION SPEECH CLIPPER.** The obvious advantages of speech clipping may be obtained in an existing amplitude modulated transmitter by including a satisfactory clipper unit between the first and second stages of the speech amplifier.

Figure 2-5 shows a 2-crystal clipper circuit which may be connected conveniently in any speech amplifier. The original gain control ( $R_A$ ) of the amplifier becomes the clipper control. This control is set by experiment to the desired level at which clipping is to take place and is not disturbed afterward. A second potentiometer ( $R_B$ ) is installed as the amplifier gain control. The 1N35 duo-diode unit supplies two factory-matched crystals for this circuit.

The filter, consisting of a choke and three capacitors in the plate circuit of the 2nd speech amplifier stage, rounds off the speech waves after the clipping operation has squared them. This filter thus removes objectionable harmonics.

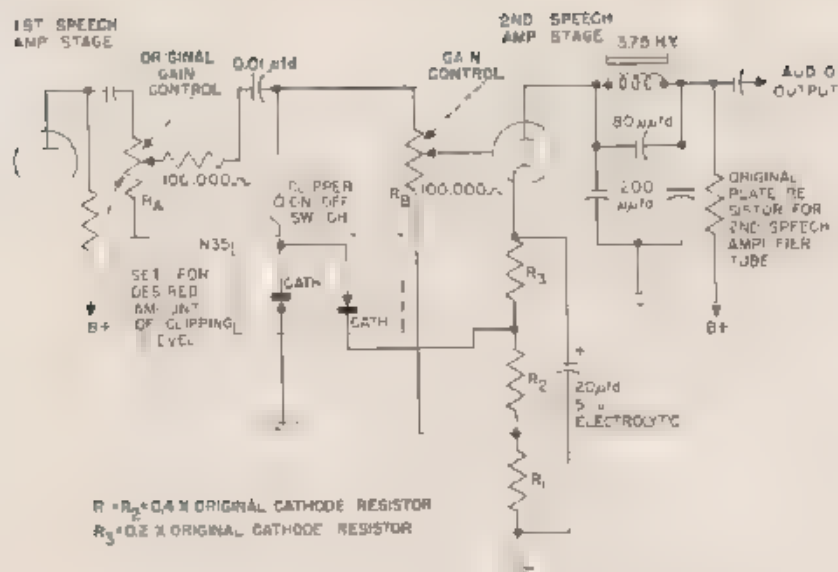


Figure 2-5. PREMODULATION SPEECH CLIPPER

**2.6 LOW-VOLTAGE BIAS SUPPLY.** Fixed grid bias voltages between 1 and 3 volts for audio amplifiers may be obtained from the 6.3 volt tube heater terminals in the amplifier through a crystal rectifier and filter.

Figure 2-6 shows a 4-crystal, full wave bridge circuit which makes an excellent bias supply which is compact and requires no attention.

The dc output voltage may be varied by changing the resistance value of  $R_2$ . As  $R_2$  is decreased, the output voltage decreases, and vice versa.

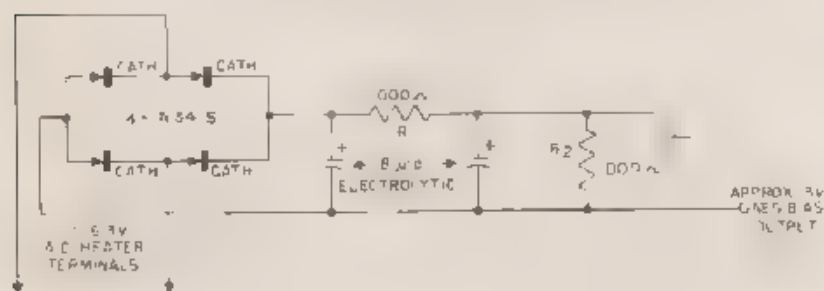


Figure 2-6. LOW-VOLTAGE BIAS SUPPLY

## CHAPTER 3

### INSTRUMENTS AND GADGETS

**3.1 SIMPLE SIDEBAND GENERATOR.** Figure 3-1 shows four matched crystal diodes connected in a "ring modulator" circuit. In lieu of four separate crystals, a Sylvania Type 1N40 or 1N41 Varistor may be used. The Varistor is a small, compact unit containing four matched diodes.

In this circuit, the rf carrier is fed into one pair of terminals, and the modulation (usually an audio frequency) into the other pair. The carrier is suppressed by the circuit action and accordingly does not appear in the output. The output contains only the upper sideband and lower sideband.

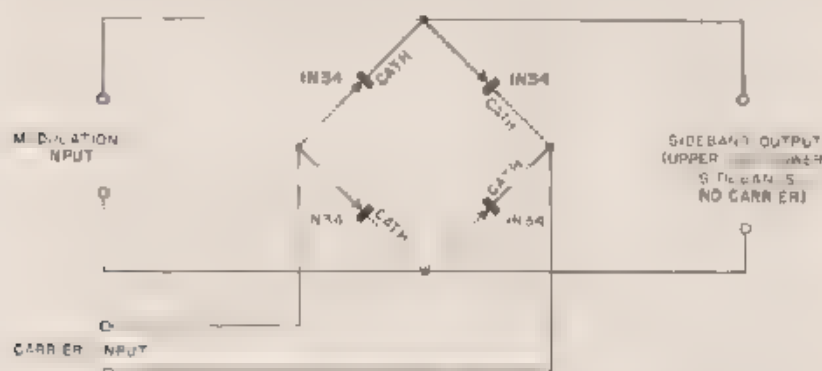


Figure 3-1. SIMPLE SIDEBAND GENERATOR

The upper sideband consists of the carrier frequency plus the modulating frequency. The lower sideband consists of the carrier frequency minus the modulating frequency. Thus; if the carrier is 1000 kc and the modulating frequency 1000 cycles, the upper sideband is 1001 kc and the lower sideband 999 kc. If desired, a suitable filter may be connected in the output to eliminate (suppress) one of the sidebands and pass the other. In this way, single sideband output may be obtained.

**3.2 TUBELESS DC AMPLIFIER.** This circuit (See Figure 3-2) is another application of the 4-crystal ring modulator. In this case, however, a dc voltage is substituted for the carrier. An ac voltage of  $1\frac{3}{4}$  volt, derived from half of a 2 $\frac{1}{2}$ -volt filament transformer secondary, is delivered to the 4-crystal circuit as the modulating voltage.

The ac voltage switches the dc voltage on and off at a rate equal to the ac frequency in much the same manner that a mechanical vibrator



might interrupt the dc circuit. This interrupted dc voltage then is stepped up through transformer  $T_2$  and induces an ac voltage across the secondary of this transformer. The fifth 1N34 rectifies this voltage and delivers it to a vacuum tube voltmeter such as the Sylvania Polymeter Type 221. The Polymeter should be switched to the dc indicating position. Thus, a small dc voltage may be stepped up to a value high enough to be read on the scale of the meter. The amount of amplification obtained depends upon the turn ratio of transformer  $T_2$ .

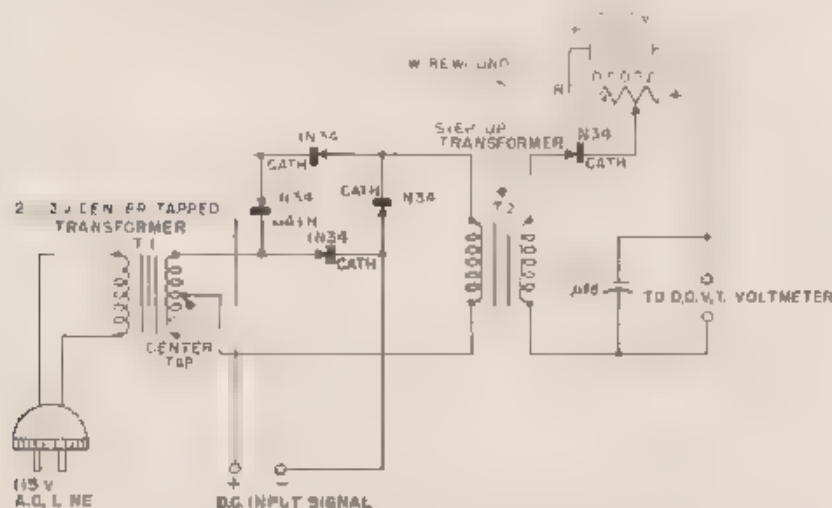


Figure 3-2. TUBELESS DC AMPLIFIER

To operate the device: (1) Set the Polymeter to zero on its lowest range. (2) Plug the amplifier circuit into the ac line and connect the voltmeter to the amplifier output terminals. (3) The meter will be deflected upward. Adjust potentiometer R to bring the meter pointer back to zero. (4) Apply the unknown voltage to the dc input terminals of the amplifier. (5) Read the voltage on the meter and divide this value by the turn ratio of the transformer to obtain the true value of the unknown voltage.

Best accuracy will be obtained if accurately-known small voltage values are fed into the amplifier and their corresponding meter deflections noted on a chart or graph.

**3.3 VOLTAGE MULTIPLIER CIRCUITS.** Figure 3-3 shows voltage doubler, tripler, and quadrupler circuits employing crystal diodes. These circuits are especially useful, since they can be operated at radio frequencies as well as at power-line and audio frequencies. At frequencies between 60 and 10,000 cycles, use 8- $\mu$ fd electrolytic capacitors throughout. At all higher frequencies, use 0.01- $\mu$ fd mica capacitors.

At low output current drains, the doubler circuit will deliver a dc voltage equal approximately to 2.8 times the r.m.s. value of the ac input voltage. The tripler dc output voltage will equal 4.2 times the ac input voltage. The quadrupler dc output voltage will equal 5.6 times the ac input voltage.

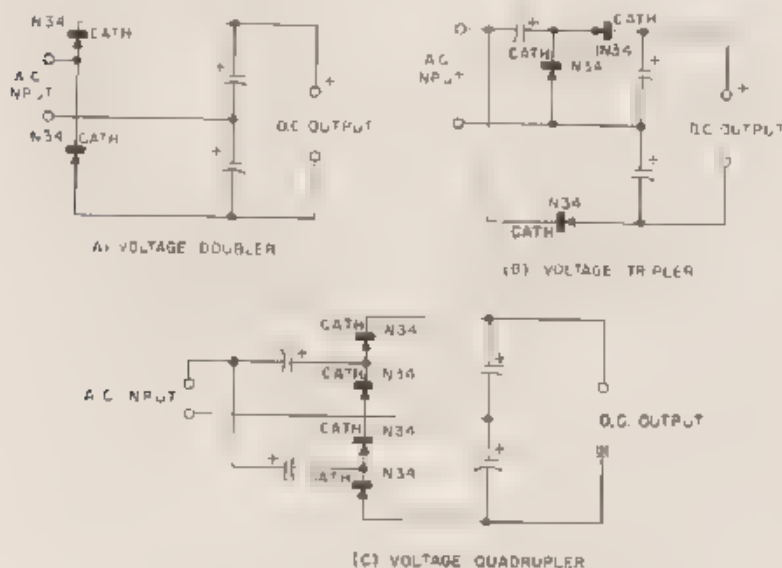


Figure 3-3. CRYSTAL VOLTAGE MULTIPLIER CIRCUITS

**3.4 AUDIO FREQUENCY METER.** This instrument (See Figure 3-4) will identify an unknown audio frequency directly in cycles per second. The circuit is "balanced" in a manner similar to the balancing of a bridge. The Wien bridge circuit is employed.

In operation, the unknown frequency is fed into the audio input terminals and the main dial, which is attached to the dual potentiometer.  $R_1$ - $R_2$  is adjusted for null (lowest l.p. of microammeter M). Then, an adjustment of auxiliary potentiometer  $R_3$  will sharpen the null point without upsetting the calibration. At this point, the unknown frequency is read from the calibrated  $R_1$ - $R_2$  dial. The frequency range of the instrument is 25 to 10,000 cycles.

The audio frequency meter is easy to build and requires no critical components, except the capacitors, each of which should have 1% tolerance.

The instrument may be calibrated by feeding in various known frequencies (obtained from an audio oscillator) between 25 and 10,000 cycles, adjusting  $R_1$ - $R_2$  and  $R_3$  for null, and marking each frequency setting on the dial of  $R_1$ - $R_2$  at corresponding null points. If an oscillator



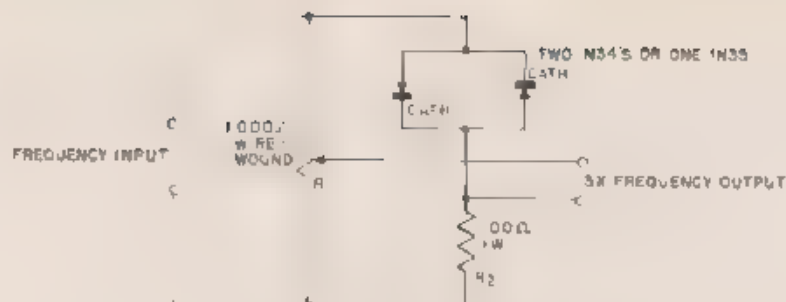


Figure 3-5. FREQUENCY TRIPLER

The resistance of either section,  $R_4$  or  $R_5$  may be measured, since both sections read the same or very nearly so.

**3.5 FREQUENCY TRIPLER.** Figure 3-5 shows a simple non-linear bridge circuit for tripling any frequency fed into its input terminals. This circuit is recommended for use at low ac levels, up to  $1\frac{1}{2}$  volts r.m.s. The output is not true sine wave.

The circuit is based on the fact that the bridge, having a crystal rectifier as one arm, may be balanced at only one voltage. This is because a crystal resistance changes with voltage. Consequently, as an applied ac half-cycle rises from zero and falls back to zero, the null voltage value is passed twice and the output voltage accordingly is zero four times during this half cycle. The output frequency thus is  $1\frac{1}{2}$  cycles for each input half-cycle. By connecting two crystals back-to-back, as shown in

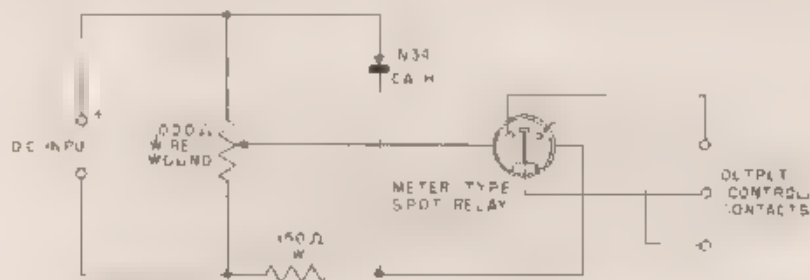


Figure 3-6. TWO-WAY RELAY OPERATING AT TWO DIFFERENT VALUES OF AN INCREASING OR DECREASING DC VOLTAGE

Figure 3-5, each half of the applied ac cycle is multiplied by  $1\frac{1}{2}$ , resulting in a total multiplication of 3. This accounts for the tripling action.

**3.6 TWO-WAY RELAY CIRCUIT.** A non-linear crystal bridge, similar to the one just described in Section 3.5, may be used to operate

a single-pole double-throw ("left-right" type) dc relay at two different values of voltage, one higher than the other. This is convenient in many forms of signalling or indicating set ups in which a control voltage rises from one value to another and must give indication of one voltage without interfering with the other.

In operation, set the bridge initially (by adjusting the 1000-ohm potentiometer) at the lowest value of input voltage at which the relay is to close. When the circuit is adjusted properly, the relay armature will swing over to one contact. As the input voltage then is increased, the bridge will pass through null, due to changing crystal resistance, whereupon the relay will open. As the voltage is increased farther, the crystal resistance will undergo additional change and the bridge will unbalance in the opposite direction causing the relay to close on the other side.

Various phenomena, such as temperature, current, and frequency variations, may be converted into voltage changes and made to operate this relay to sound alarms or to record changes.

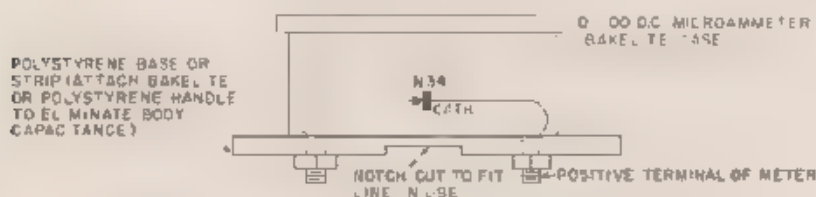


FIGURE 3-7. STANDING WAVE INDICATOR FOR TWIN-LEAD RF TRANSMISSION LINE

**3.7 STANDING WAVE INDICATOR.** Figure 3-7 shows a handy arrangement of a crystal diode and dc microammeter for testing for standing waves along a flat, twin-lead transmission line such as the 100-ohm lines used between amateur transmitters and antennas. No direct electrical connection to the line is required.

The crystal diode is wired in parallel with the meter. The notch or slot cut into the polystyrene base back of the meter is just wide enough to clear the transmission line edges comfortably. As the instrument is slid along the line, with the transmitter in operation, the meter will deflect up-scale to indicate peaks and down scale to indicate nulls.

**3.8 SIMPLE FIELD STRENGTH METER.** This instrument (Figure 3-8) is indispensable for checking the gain and field pattern of transmitting antennas and for checking for presence of harmonics and interference. The entire unit may be built into a small metal radio utility box.

A Type 1N56 crystal diode is recommended, since this crystal gives more dc output current than the 1N34 and accordingly will produce a higher meter deflection with a given rf signal.

Commercial short-wave plug-in coils may be used. Special coils for the ultra-high frequency amateur bands may be wound according to specifications found in the amateur radio handbooks.

If the tuning dial of the field strength meter (attached to tuning capacitor C) is calibrated directly in megacycles by means of an rf test oscillator or signal generator, the instrument will be suitable as an absorption wavemeter for frequency measurements.

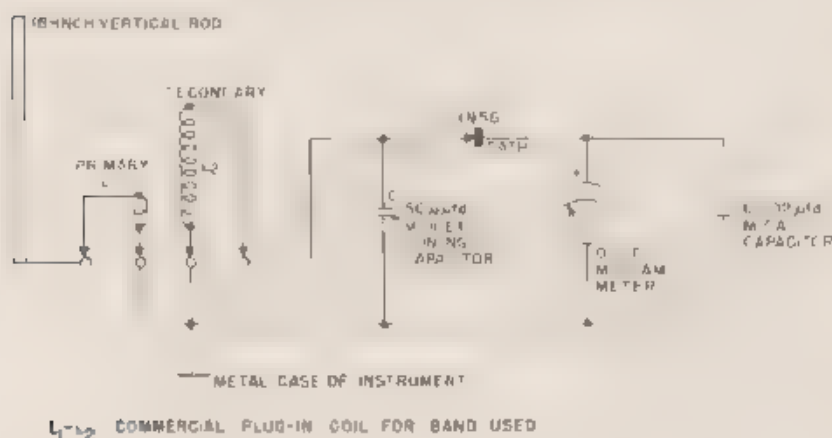


Figure 3-8. SIMPLE FIELD STRENGTH METER

**3.9 SENSITIVE FIELD STRENGTH METER.** Sensitivity of the field strength meter may be increased by employing (1) full-wave detection with two matched crystals and (2) a sensitive de microammeter in place of the milliammeter.

The full-wave detector circuit in Figure 3-9 consists of a center-tapped, double-tuned secondary coil ( $L_2$ ) and a 1N35 dual crystal diode.

Instructions are given in Figure 3-9 for winding the required tapped, plug-in coils for continuous coverage of the frequency range 3.5 to 200 megacycles.

**3.10 AE-RF AMMETER.** A radio frequency ammeter which can be used at frequencies up to 100 megacycles or better is a handy device for the amateur station, laboratory, or radio workshop. A simple meter of this type is shown in Figure 3-10.

This instrument consists basically of a crystal voltmeter (crystal diode plus a de milliammeter) connected so as to measure the voltage drop across a non-inductive 1 ohm resistor. The unknown current flowing through this resistor sets up the voltage drop. By Ohm's Law, the voltage measured across the 1-ohm resistor will be equal to the current flowing through the resistor. Consequently, if the meter is calibrated 0.1 volt, it will indicate also 0.1 ampere.



Calibration of the instrument is simple. Apply an accurately-known ac voltage of 1 volt (60 cycles will do, but 1000 cycles will be better) to the input terminals. Then adjust the 300-ohm rheostat for full-scale deflection of the milliammeter. The meter indicates at full scale an current flow of 1 ampere through the 1-ohm resistor. Reduce the input voltage to 0.9 volt and record the milliammeter reading. Repeat at various lower-voltage points in 1/10-volt steps, to obtain a calibration curve similar to the one shown in Figure 3-10. This chart then may be referred to when making measurements, to convert milliamperes indications to amperes. Or a special ampere scale may be prepared from it for the milliammeter.

Because of the wide frequency range of the crystal, the ammeter can be operated at radio as well as audio frequencies.

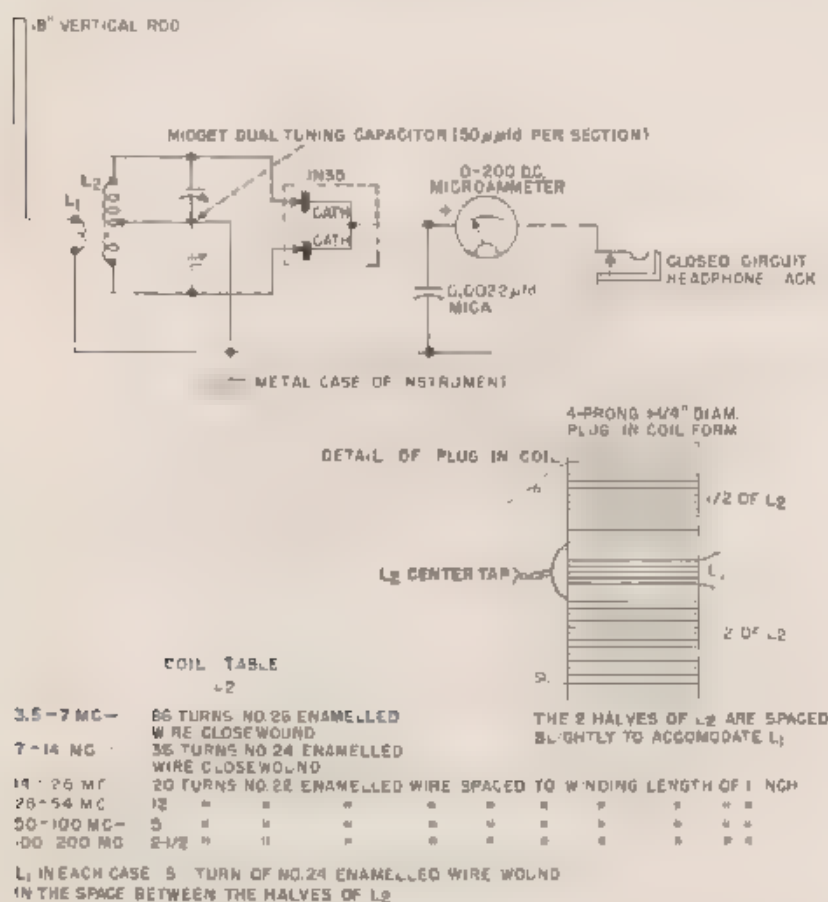


Figure 3-9. SENSITIVE FIELD STRENGTH METER

### 3.11 EXTERNAL MODULATOR FOR SIGNAL GENERATORS

Most rf signal generators and test oscillators are modulated internally at an audio frequency of 400 cycles. It often is desirable to modulate the rf signal at some frequency other than 400 cycles, but this entails tampering with the internal wiring of the oscillator.

The simple 4-crystal device shown in Figure 3-11 can be connected to the rf output terminals of the signal generator and to the output terminals of any audio oscillator. It will combine the two signals and deliver a radio-frequency signal modulated at the frequency of the audio oscillator. In this way, the signal generator circuit need not be altered in any

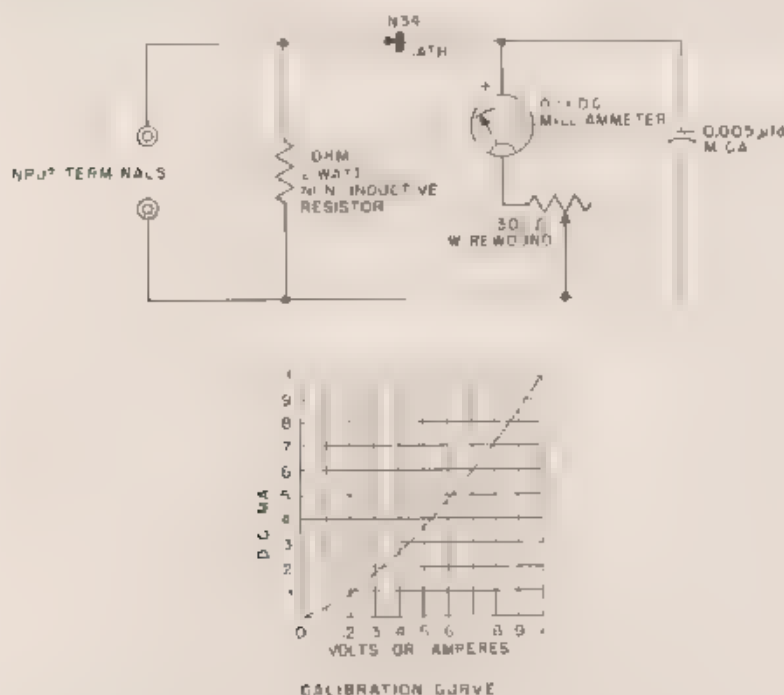


Figure 3-10. AF-RF AMMETER (0-100 MC)

manner. The circuit is a type of diode modulator similar to those described in Sections 3.1 and 3.2.

When using the device, connect the output terminals of the signal generator to the rf input terminals of the modulator circuit. Switch-off the internal modulation of the signal generator so as to obtain a c.w. signal. Connect the audio oscillator output terminals to the audio input terminals of the modulator. Connect the receiver, or other equipment under test, to the modulated rf output terminals. Adjust the output voltage control of the audio oscillator to give the desired modulation intensity.

Actually, this modulator suppresses the carrier frequency and delivers the two sidebands which result from the amplitude modulation process. But for audio frequencies up to about 2500 cycles, the modulated signal will be tuned in on a receiver dial at the same point as the regular signal generator signal. Only at modulation frequencies above 5000 cycles will the receiver dial show the two sidebands as separate signals, one above and one below the carrier frequency point.

**3.12 RF PROBE.** DC vacuum tube voltmeters now are standard equipment in laboratories, stations, and shops. A number of these instruments have no provision for checking rf voltages. It is advantageous to be able to measure rf voltages in receiver signal tracing and in various forms of experimental work.

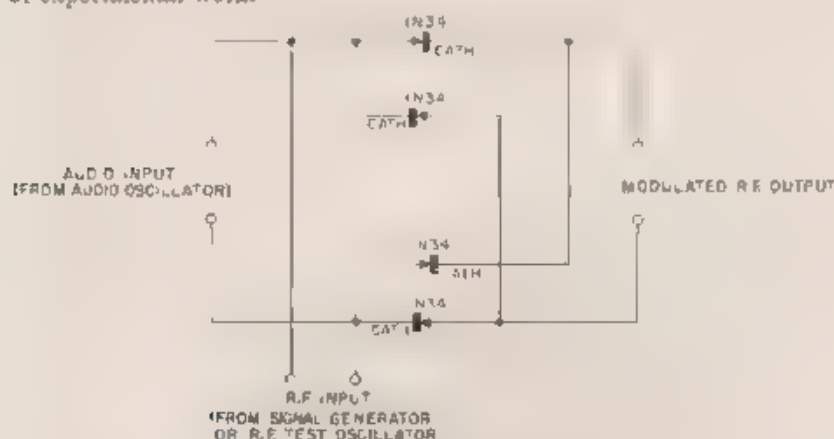


Figure 3-11. EXTERNAL MODULATOR FOR RF TEST OSCILLATOR

Figure 3-12 shows details of a crystal-type rf probe which may be used in conjunction with any dc vacuum tube voltmeter. This is one of many types of such probes which have been developed since introduction of the germanium crystal diode.

This probe will handle frequencies up to 200 megacycles. The maximum voltage which may be checked with it will be 20 volts r.m.s. The 0.01- $\mu$ fd input capacitor isolates the crystal and protects it and the circuit from harmful dc voltages which may be present in the circuit under test. The indication obtained on the dc scale of the VTVM will be equal to approximately 1.4 times the r.m.s. value of the applied rf voltage. For best accuracy, the probe should be calibrated by applying to it a number of accurately-known rf voltages (checked by means of another voltmeter) and observing the corresponding readings of the dc vacuum tube voltmeter.

**3.13 AUDIO EXTRACTOR FOR SIGNAL GENERATORS.** While all signal generators and rf test oscillators are modulated internally, only

a few of these instruments deliver an audio output signal in addition to rf. The audio voltage is useful for testing audio amplifiers and the audio channels of radio receivers, and for various other experimental purposes requiring a single test tone.

The circuit in Figure 3-13 extracts the audio signal from the modulated rf output of a signal generator. This device, which may be built

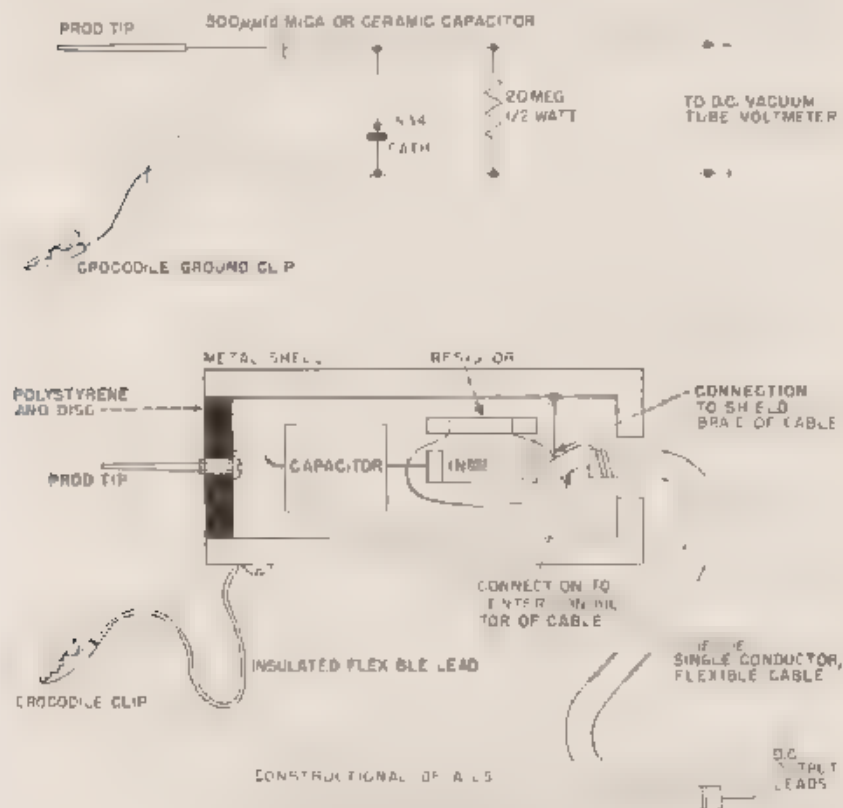


Figure 3-12. RF PROBE FOR DC VACUUM TUBE VOLTMETER

easily into a small can or box, is connected to the output terminals of the signal generator and requires no tampering with the internal circuit of the instrument.

**3.14 TUBELESS TONE GENERATOR.** When an ac signal is applied to two crystals connected in a full wave rectifier circuit, the output current delivered by the crystals is a pulsating dc having twice the frequency of the applied voltage. The full-wave circuit thus becomes a frequency doubler. A second full-wave circuit, added in cascade to the first one, will double the frequency again, thereby delivering 4 times the

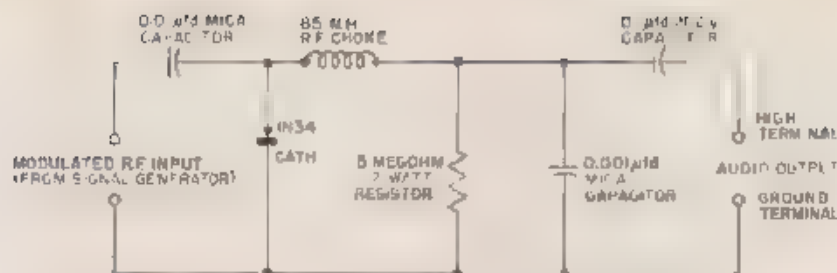


Figure 3-13. AUDIO EXTRACTOR  
FOR RF SIGNAL GENERATORS

frequency of the input signal. Any additional full-wave circuit will double the frequency it receives, and the multiplication process may be carried on to a point at which the output voltage finally becomes too low to be useful. In this way, a number of stages may be cascaded, each stage output giving a tone which is an even multiple of the input frequency.

Figure 3-14 shows a circuit of this kind for doubling and quadrupling any audio frequency within the range of the coupling transformers. The input signal may be taken from the ac power line or from an audio oscillator. Three audio transformers and four crystal diodes are employed. If the builder desires, two Sylvania 1N35 duo-diode units may be used in place of the four separate 1N34's.  $T_1$  and  $T_2$  are ordinary interstage audio transformers with single-ended primaries and push-pull secondaries.  $T_3$  has a single-ended primary and secondary.

A closed-circuit jack in the first stage delivers output at twice the input signal frequency, while the output terminals of transformer  $T_3$  delivers 4 times the input frequency. Thus, if a 60-cycle voltage is applied to the signal input terminals, the jack will deliver 120 and the output terminals 240 cycles.

The output of this tone generator is not true sine wave. If the builder requires pure tones, it will be necessary to employ bandpass filters in the output circuits to transmit the desired frequency only.

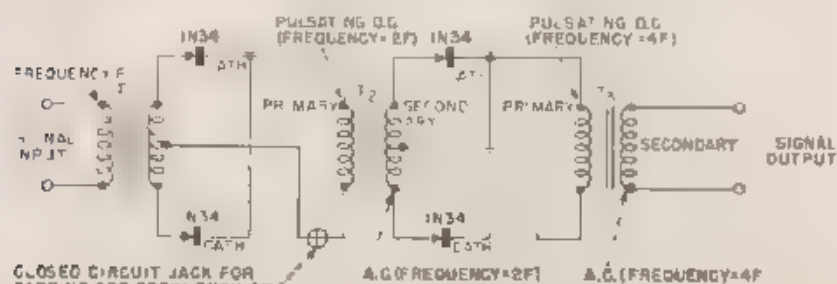


Figure 3-14. TUBELESS TONE GENERATOR

**3.15 TUBELESS AUDIO OSCILLATOR.** When a germanium diode is connected in the "back direction" (that is, with its cathode to the positive dc power supply terminal) in a suitable circuit, it will oscillate, provided the applied dc voltage is high enough to reach the negative resistance region in the reverse-conduction curve of the crystal.

An audio oscillator circuit applying this principle is shown in Figure 3-15. The constants of this circuit are such that the frequency of oscillation is approximately 1200 cycles. The frequency may be increased by decreasing the capacitance of the capacitor, and may be lowered by increasing the capacitance. This circuit delivers an output of about 30 volts r.m.s. across a pair of 2000-ohm headphones.

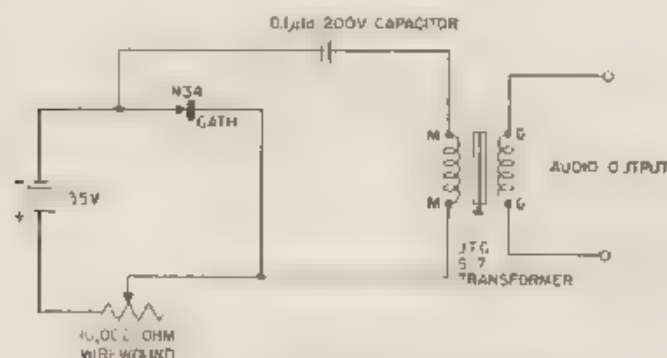


Figure 3-15. TUBELESS AUDIO OSCILLATOR

Adjustment of the oscillator is very simple: Rotate the 10,000-ohm potentiometer until the point is reached at which the circuit breaks into oscillation. Then, reduce the potentiometer setting slightly.

This oscillator is suitable only for intermittent use, such as it might receive in signal injection or signal tracing in audio amplifier testing, or as a code practice oscillator. Sustained operation of the crystal in its oscillating negative resistance condition produces appreciable internal heating and will ultimately destroy the unit. Nevertheless, this circuit will be found extremely useful, especially for applications requiring a miniature instrument.

**3.16 CRYSTAL DIODE WAVE SHAPER.** In various forms of radio and electronic testing, it is desirable to have a signal consisting either of positive peaks only, negative peaks only, or square waves. Pulse generators for producing special signals of these types are complicated equipment and therefore costly.

The circuit illustrated in Figure 3-16 takes a sine-wave signal, which may be obtained easily from an audio oscillator or from a stepdown transformer operated from the ac power line, and converts it into either one of the special signals described above. Whole pulses obtained in



this manner are not perfect, they will be suitable for a wide variety of experimental work.

Operation of the circuit is based upon the *clipper* or *limiter* principle. When both switches are open, the output voltage of the device has the same sine-wave shape as the input signal (See pattern A). When switch  $S_1$  is closed and  $S_2$  opened, the first crystal diode and 1½-volt cell clip the negative peaks from the input signal and deliver an output signal consisting almost entirely of positive peaks (See pattern B). When

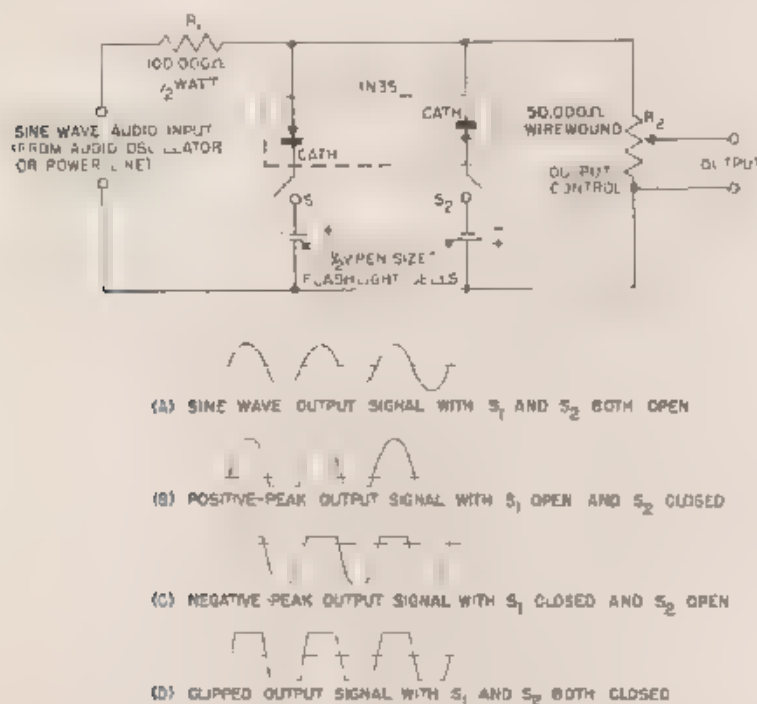


Figure 3-16. CRYSTAL DIODE WAVE SHAPER

$S_1$  is closed and  $S_2$  open, the second diode and cell clip the positive peaks from the input signal and deliver an output signal consisting almost entirely of negative peaks (See pattern C). When both  $S_1$  and  $S_2$  are closed, positive and negative peaks are both clipped and the output signal is very nearly a square wave. (See pattern D). Best squareness will be obtained when the input signal is at least 30 volts r.m.s.

Potentiometer  $R_2$  is an amplitude control for adjusting the strength of the output signal to suit individual conditions.

When the device is not in use both switches must be thrown to their open position to prevent battery drain through the crystals.

**3.17 AF-RF WATTMETER** The instrument shown in Figure 3-17 will indicate audio-frequency or radio-frequency power up to 100 watts, either directly on a specially-drawn meter scale or by reference to a calibration curve such as the one shown below the circuit diagram. This wattmeter may be built into a small metal meter box.

After the circuit has been wired, the instrument must be calibrated in

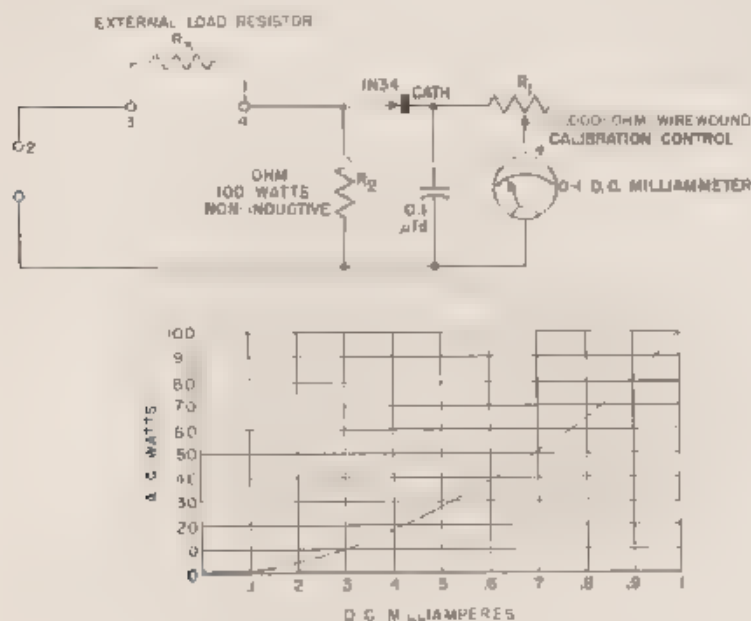


Figure 3-17. AF-RF WATTMETER

the following manner. Disconnect temporarily one end of resistor  $R_L$ , and short-circuit terminals 3 and 4. Apply an accurately known 10-volt r.m.s. signal (60 cycles will do) to input terminals 1 and 2, and adjust rheostat  $R_1$  for exact full scale deflection of the milliammeter. Because of the linearity of the crystal-meter combination in this voltage range only the single-point check need be made. Do not disturb the setting of  $R_1$  unless a recalibration is required later on. Remove the signal voltage from terminals 1 and 2, remove the short-circuiting jumper from terminals 3 and 4, and reconnect resistor  $R_L$ .

This wattmeter is very simple to use. The following procedure is recommended: (1) Determine the output impedance of the amplifier, oscillator, or other device to be tested. (2) Connect to terminals 3 and 4 a 100-watt resistor (preferably non-inductive) which has a resistance value equal to 1 ohm less than the impedance of the power-delivering device. It may not always be possible to obtain a resistor having the exact resistance value required. In this case, it will be necessary to use a

wirewound unit with a slider set to the desired ohmic value. If the output impedance of the power-delivering device is 1 ohm, do not use an external resistor at all. Instead, short-circuit terminals 3 and 4. (3) Connect terminals 1 and 2 to the output terminals of the power-delivering device. (4) Read output watts on the meter scale, or by reference to the curve given in Figure 3-17. (5) Multiply this meter reading by the output impedance of the device under test when this impedance is higher than 1 ohm.

When checking the power output of an audio amplifier, disconnect the loudspeaker voice coil from the amplifier, connect terminals 1 and 2 of the wattmeter in place of the voice coil, and connect a resistor to terminals 3 and 4 equal in ohmage to the voice coil impedance minus 1 ohm. The external resistor must be rated to handle at least 2 times the power output of the amplifier.

**3.18 SENSITIVE AF-RF SIGNAL TRACER.** Numerous crystal diode signal tracers have been designed by radio writers. The instrument shown in Figure 3-18 has the advantages that it will give meter readings, as well as headphone signals, at very low values of signal input voltage. This tracer may be used for trouble shooting in all of the rf, detector, oscillator, if, and audio stages of a radio receiver, and in audio amplifier systems.

A Type 1N54 high-efficiency diode is used for improved performance. The 0.01  $\mu$ fd input capacitor protects the diode, headphones, and meter from any dc voltage which may be present in the circuit under test. The 200,000-ohm rheostat acts as a gain control to adjust the meter current.

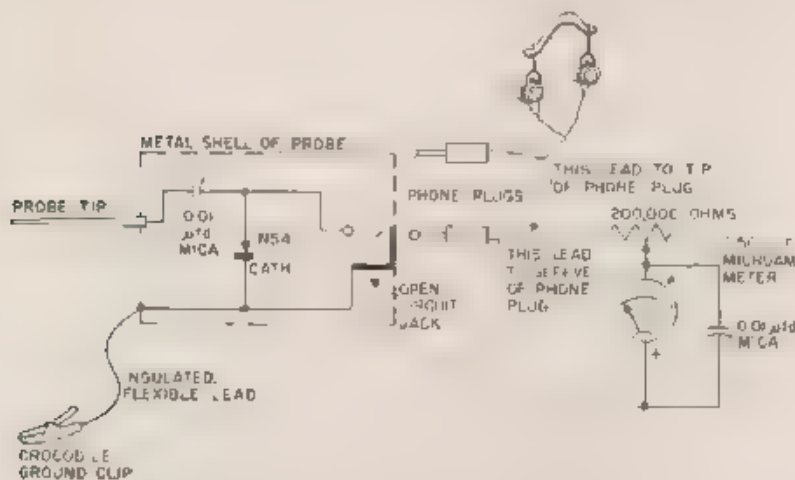


Figure 3-18. SENSITIVE AF-RF SIGNAL TRACER

to a readable value. The meter circuit is plugged into the jack in the end of the handle of the exploring probe for visual indications; the headphones for aural indications. A modulated signal is necessary to operate the headphones, but the meter will be actuated by either a modulated or unmodulated signal.

**3.19 DISTORTION METER.** This instrument (See Figure 3-19) can be used to measure the distortion percentage of audio amplifiers and oscillators. It consists of a bridged-T null network and a 3-range crystal voltmeter. With Switch  $S_2$  in its top position, the instrument range is 0-100% distortion; with  $S_2$  in its center position, the range is 0-10%; and with  $S_2$  in its lower position, the range is 0-5%. The instrument operates at 400 cycles. The null network (consisting of the choke, two

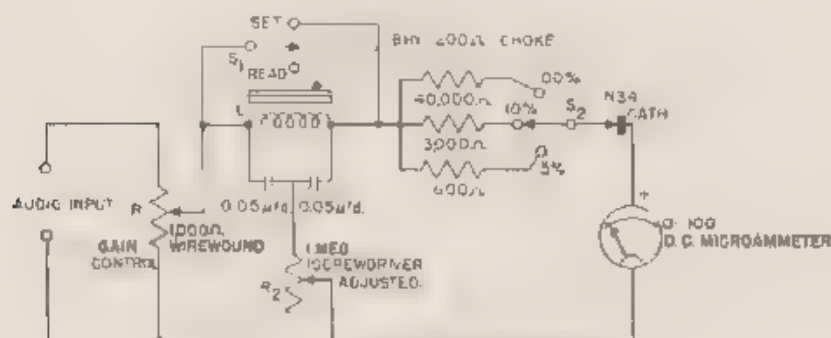


Figure 3-19. DISTORTION METER

0.05- $\mu$ fd capacitors, and 1-megohm rheostat) removes the 400-cycle fundamental frequency. Any voltage remaining is due to harmonics and is measured by the crystal voltmeter.

After the instrument has been completed, it must be calibrated in the following manner: The microammeter needs no special calibration on the 0-100% scale, it being read directly in percentage. The 0-10 and 0-5 scales must be calibrated separately, however, because of non-linearity of the crystal at the lower voltages. Apply a variable-voltage source to the audio input terminals of the distortion meter (60 cycles will do), set gain control  $R_1$  to the top of its range, throw switch  $S_1$  to its SET position, and set switch  $S_2$  to its 10% position. Adjust the voltage in 1/10-volt steps from 0.1 to 1 volt, marking the meter scale or making a calibration chart. The voltage scale then will show distortion percentages in the following manner:

RMS INPUT VOLTS	% DISTORTION
0.1	1
0.2	2
0.3	3
0.4	4
0.5	5
0.6	6
0.7	7
0.8	8
0.9	9
1.0	10

Next switch  $S_2$  to its 5% position and apply a variable input in 1/10-volt steps from 0.1 to 0.5 volt and prepare another meter scale or reference chart as follows:

RMS INPUT VOLTS	% DISTORTION
0.1	1
0.2	2
0.3	3
0.4	4
0.5	5

For the initial adjustment: (1) Connect the input terminals of the distortion meter to a variable-frequency audio oscillator. (2) Set output control of oscillator to maximum. (3) Throw switch  $S_1$  to SET. (4) Set oscillator dial to 400 cycles. (5) Adjust gain control  $R_1$  (with  $S_2$  on 5% range) for full-scale deflection of microammeter. (6) Throw  $S_2$  to READ, noting drop in meter deflection. (7) Tune oscillator above and below 400 cycles, noting that meter deflection passes through null. Retune dial carefully for lowest dip in microammeter reading. This setting of oscillator dial should be 400 cycles. If it is not, due to inaccuracies in the capacitors and choke in the distortion meter, mark exact point on oscillator dial for quick re-tuning. (8) Adjust rheostat  $R_1$  carefully for an improvement in the null. (9) When the best null point is obtained, the meter very likely will not read exactly zero. The reading at this point indicates the distortion percentage of the oscillator. This figure must be recorded, since it should be subtracted from any distortion readings obtained later on when this oscillator is employed.

To use the distortion meter, follow the instructions: (1) Connect the audio oscillator (set to the 400-cycle test frequency) to the input terminals of the amplifier under test. (2) Connect the input terminals of the distortion meter to the output terminals of the amplifier—that is, across the loudspeaker voice coil or across a substitute load resistor having the ohmic value of the voice coil impedance). (3) Set  $S_1$  to SET. (4) Set  $S_2$  to 100%. (5) With the oscillator and amplifier in operation, adjust  $R_1$  for a meter reading. (6) Set  $S_2$  to READ. (7) Read distortion percentage on the meter scale or by reference to the calibration chart. If a readable deflection is not obtained, throw  $S_2$  to a lower range.

**3.20 SIMPLE SELECTIVE TELEPHONE CIRCUIT.** Figure 3-20 shows a simple wire telephone circuit by means of which either one of two remote listeners (both on a single, 2-wire line) may be addressed without the other one hearing. This scheme will appeal to Scouts, summer campers, and house-to-house telephone enthusiasts.

The circuit operates in this way: Listener A has a crystal diode "forward connected" in series with his headphones. In the forward direction, this crystal introduces very little resistance into the circuit and station A accordingly hears clearly whatever is said into the microphone. Listener B, however, has a crystal "back connected" in series with his headphones. In the back direction, this crystal introduces a very high resistance into that portion of the circuit which includes headphones B. The currents flowing through these headphones therefore are too small to reproduce sound. Station B hears nothing.

In order to reverse the procedure and talk to station B, to the exclusion of A, simply reverse the polarity of the battery at the sending station.



Figure 3-20. SIMPLE SELECTIVE TELEPHONE CIRCUIT

whereupon the crystal A becomes a high resistance and cuts out that station, while B receives.

For short distances, the battery can be a  $1\frac{1}{2}$ -volt dry cell. For longer distances, the voltage must be increased to overcome the resistance losses in the wires. The best voltage for a given distance must be determined experimentally. For simplicity, only a one-way circuit is shown in Figure 3-20.

**3.21 SELECTIVE TELEGRAPH CIRCUIT.** By employing the same principle described in Section 3.20, a 2-wire line may be used for sending telegraph signals separately to either one of two receiving stations connected across the line. Instead of telegraphing, a bell or other alarm may be operated at will at either one of the stations without disturbing the other. Figure 3-21 shows the circuit used.

Each receiving station has a sensitive relay and crystal diode connected in series across the 2-wire line. At Station A, the crystal is forward-connected and allows between 2 and 3 milliamperes to flow through its

associated relay coil when the key or switch is closed at the transmitting station. This current is sufficient to operate the relay. At Station B, the crystal is back-connected and passes only about 100 microamperes through its relay coil. This small current is insufficient to pick up the relay. When the polarity of the transmitting battery is reversed, the relay at Station B is actuated because its crystal anode then is connected to the positive battery terminal (forward connection), and the one at Station A is dead.

The relays may be used to operate telegraph sounders, bells, horns, lamps, locks, valves, or other electromechanical or electrical devices.

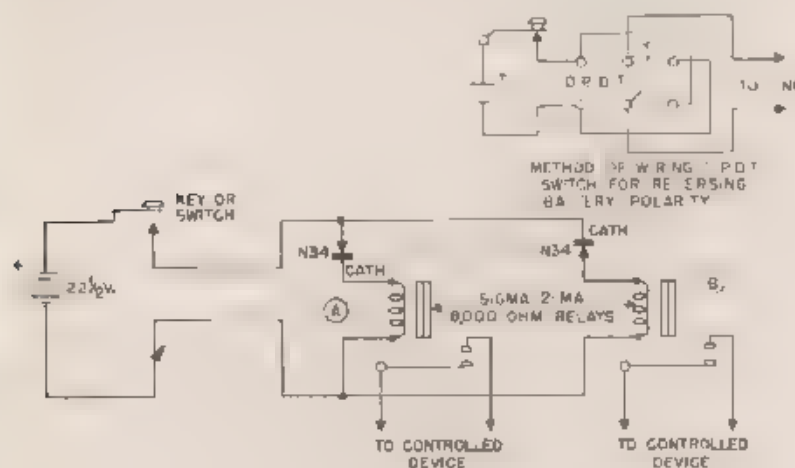


Figure 3-21. SELECTIVE TELEGRAPH CIRCUIT

The 22 1/2-volt battery is adequate for operation up to several hundred feet when the wire used in the line is at least No. 18 in size. For longer-distance communication, the battery voltage must be increased, the most suitable voltage being determined by experiment.

**3.22 MODULATION AND CARRIER SHIFT METER.** The instrument shown in circuit schematic in Figure 3-22 will give direct indications of modulation percentage on either positive or negative peaks, and will indicate carrier shift when used to monitor an amplitude-modulated radio transmitter. This is the circuit of the popular Sylvania Mod-meter.

The input terminals of this instrument are link coupled (by means of a small pickup coil) and twisted pair or coaxial line) to the final amplifier plate tank coil of the modulated transmitter. With the ganged switch,  $S_1$ , thrown to its rf position, the coupling between the pickup coil and the plate tank is varied while the 100- $\mu$ fd. tuning capacitor is adjusted to deflect the milliammeter to a reference point near full-scale. This reading will not change unless carrier shift is present in the transmitted signal.



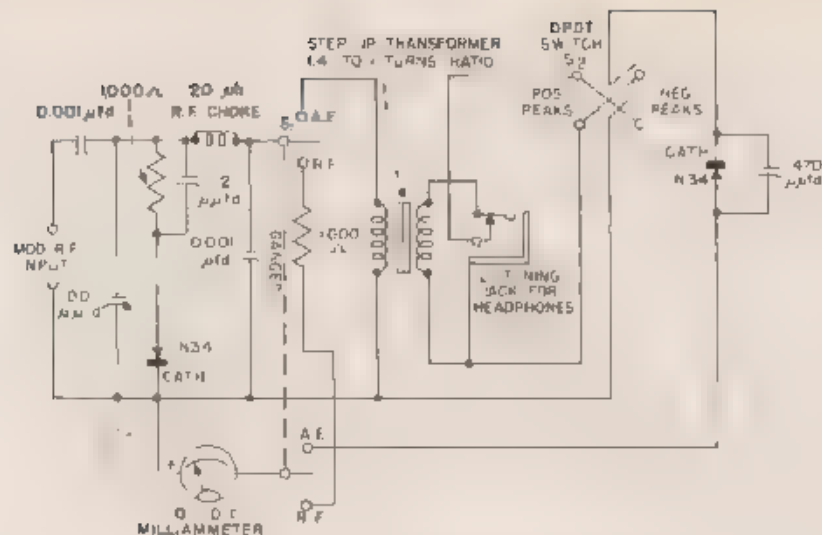


Figure 3-22. PERCENTAGE MODULATION AND CARRIER SHIFT METER

When Switch  $S_1$  is thrown to its af position, the meter will indicate modulation. The meter scale may be calibrated to read modulation percentage directly by means of modulated signals of variable percentage and an oscilloscope set up to show modulation patterns. See the Sylvania book *How to Service Radios with an Oscilloscope* for an explanation of these patterns, how to obtain them and how to interpret them. When switch  $S_2$  is thrown to its left-hand position, positive-peak modulation will be indicated by the meter. With this switch in its right-hand position, negative-peak modulation will be indicated.

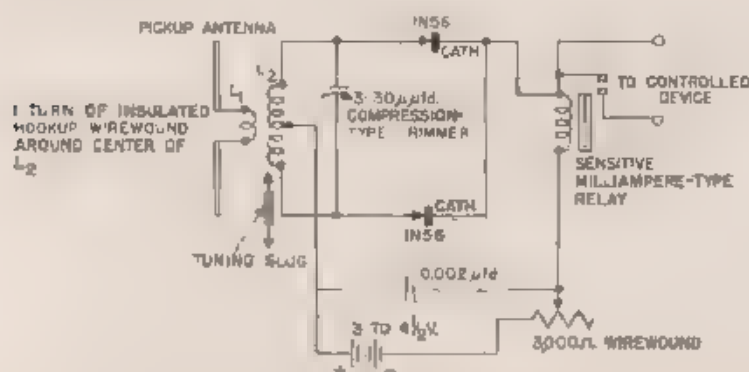


Figure 3-23. 144-MC RECEIVER FOR MODEL CONTROL

Headphones may be plugged into the closed-circuit listening jack for the purpose of monitoring the modulated signal for voice quality and for the presence of noise or hum. When making modulation percentage checks, however, the headphones must be removed.

**3.23 RECEIVER FOR MODEL CONTROL.** Figure 3-23 gives the circuit diagram of a 144-Mc-band crystal receiver for model control. This set has the particular advantage of small size and light weight, features which suit it well for airplane and small boat control.

Increased sensitivity is obtained in this circuit by the use of two Type 1N56 high-conduction crystal diodes in a full-wave detector circuit, and by use of a bias battery. The battery current through the relay coil is adjusted (without a received signal) to the point at which the relay is just about to operate. The rectified crystal voltage, due to the received signal, then will be required to furnish only the small *additional* current necessary to pick up the relay. Greater sensitivity is obtained in this way than is possible with single-crystal reception without the battery.

For simplicity and foolproof operation, a manufactured coil is specified in Figure 3-23.

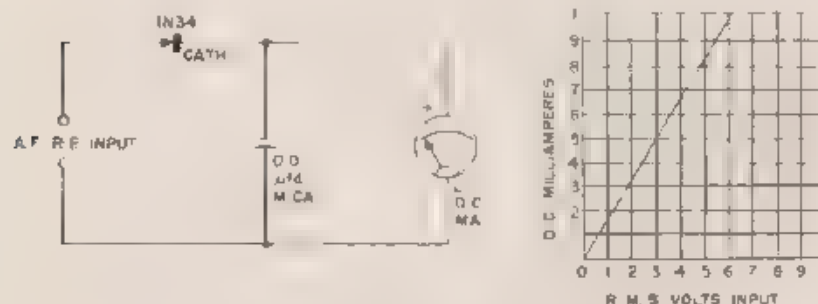


Figure 3-24. CRYSTAL VOLTMETER

**3.24 CRYSTAL VOLTMETER.** The crystal voltmeter has the advantages that it is capable of instant operation; requires no zero setting; has a wide frequency response extending from power-line frequencies to 200 megacycles or more, is compact enough to be built easily as an output indicator into other instruments such as wavemeters, oscillators, bridges, and monitors; and requires no batteries nor other power supply for its operation. Its input impedance, however, is low compared to a vacuum tube voltmeter. But this does not detract from its usefulness in many applications.

Figure 3-24 shows the simplest crystal circuit, employing a 1N34

double the length of the meter and by less of factor. This meter will find a host of uses in the radio room.

The basic range of the meter is less than 1 volt rms and is put for full scale deflection. Figure 12 shows a sample calibration curve for this instrument. The reader must calibrate his own meter however since individual crystals vary in deflection characteristics. The basic range of the meter may be extended as much as meters by use of multiplier resistors.

RATINGS AND CHARACTERISTICS  
SYLVANIA  
GERMANIUM CRYSTAL DIODES

## RATINGS AND CHARACTERISTICS

### SYLVANIA GERMANIUM CRYSTAL DIODES

Sylvania's line of germanium crystal components include nine diode types, a duo-diode and four varistor networks. All are lightweight, compact, rugged circuit elements having low shunt capacity, no contact potential and require no heater supply or mounting hardware. They have exceptional electrical stability and are strongly resistant to thermal shock.

Among the nine germanium diodes are types designed to withstand working voltages up to 50, 80, 100, 150 or 200 volts in the reverse direction, to exhibit exceptionally high back resistance or to possess a high forward conduction characteristics.

Several types are now available in either the ceramic or glass construction. The glass types are made moisture proof by the unique hermetically sealed glass cartridge. They are smaller and lighter than the ceramic types and have been designed with terminals smaller in diameter than the glass body to eliminate risk of accidental contact in side-by-side mounting.

The duo-diode Type 1N35 is a mounted pair of 1N34 diodes carefully matched for use in balanced circuits for full-wave rectification, modulation or demodulation.

Sylvania Varistor Types 1N40, 1N41, 1N42 and V403 are networks of four carefully selected and matched diodes especially designed for use as ring modulators in carrier suppression or carrier transmission circuits. In the plug-in units, Types 1N40, 1N42 and V403, the crystals are mounted in a compact metal radio tube shell. In Type 1N41, the crystals are assembled in a rectangular metal can equipped with eight soldering lugs and adapted for top or sub-panel mounting.

All Sylvania Germanium Diodes have a nominal shunt capacitance of 1  $\mu$ f; tolerate an ambient temperature range of  $-50^{\circ}$  C to  $+75^{\circ}$  C and have an average life of more than 10,000 hours.

The principal electrical ratings for each diode and the duo-diode and varistor types are shown on the accompanying table.

TYPE	1N34	1N35	1N38	1N39	1N40	1N41	1N42	1N54	1N55	1N57	1N58	1N60	1N61
Description	General Purpose Diode	Matched Diode	100-Volt Diode	200-Volt Diode	High-Resistor Varistor	Low-Resistor Varistor	Photoconductor Varistor	High-Resistor Diode	1.50-Volt Diode	High-Resistor Diode	100-Volt Diode	Video Detector Diode	Low Impedance Varistor
Continuous Reverse Working Voltage (volts max.)	60	50	100	200	25	25	50	35	150	80	100	30	40
Peak Back Voltage for Zero Dynamic Resistance (volts min.)	75	75	120	225	75	75	120	75	170	90	115	70	50
Forward Current at +1 Volt (ma min.)	5.0	7.5	3.0	3.0	12.75 (at 1.5 volts)	12.75 (at 1.5 volts)	12.75 (at 1.5 volts)	5.0	3.0	4.0	4.0	4	15.0
Average Anode Current (ma max.)	40	22.5	40	40	22.5	22.5	22.5	40	40	40	40	40	50
Maximum Peak Anode Current (ma max.)	150	60	150	150	60	60	60	150	150	150	150	150	200
Induced Surge Current (ma max., 1 sec.)	500	100	500	500	100	100	100	500	500	500	500	500	1000
Reverse Current (ma max.)	50 (at -10 v) 100 (at -50 v)	10 (at -5 v) 62.5 (at -100 v)	5 (at -3 v) 62.5 (at -100 v)	200 (at -100 v) 800 (at -200 v)	50 (at -10 v) 50 (at -10 v)	50 (at -10 v) 50 (at -10 v)	6 (at -3 v) 62.5 (at -100 v)	10 (at -10 v) 100 (at -100 v)	100 (at -100 v) 150 (at -150 v)	500 (at -75 v) 500 (at -100 v)	100 (at -100 v) 100 (at -100 v)	100 (at -100 v) 100 (at -100 v)	100 (at -100 v) 100 (at -100 v)
Shunt Capacity (pF max.)	3	3	3	3	3	3	3	3	3	3	3	3	3
Ambient Temperature Range (°C)	-50°C to +75°C for all types												
Average Life (hours)	More than 10,000 hours for all types												

\* Units are matched in the forward direction at +1 volt so that the current flowing through the higher resistance unit is within 10% of that in the lower resistance unit. Ratings are given for each unit in the forward direction. Consists of 4 thermally matched and matched germanium diodes whose resistances are matched within +2.5% in the forward direction at 1.5 volts. For additional details, the forward resistances of each pair of varistor crystals are matched within 2 ohms. Ratings shown above are for each diode.

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† Units are tested in a circuit employing an input of 1.8 volts rms at 40 mc, 70% modulation at 400 cycles. Dissipated output across a 4700 ohm resistor limited by a 500 ohm capacitor is a minimum of 1.1 volts peak to peak.

† Consists of four matched low impedance germanium diodes each of which, with a voltage of one volt impressed in the forward direction, will pass a current within one ma of the average current of the four. Ratings shown above are for each diode.

HB 9 HK

Amateur Radio Station  
HB-9 HK  
Dr. Willy Rupp, P. O. Box 72  
Kessnacht/SZ  
Switzerland